

Abstract

Objective: To determine trunk muscle activities during lifting of an object heavier than expected, which may contribute to the development of low back pain.

Design: Electromyographic evaluation of trunk muscle activities

Setting: University Spine Laboratory

Participants: Eleven healthy men (mean age \pm SD, 24.0 \pm 2.2 years)

Interventions: Trunk muscle activities were measured when the participants lifted an object with their right arm in immediate response to a light stimulus. Surface and wire electrodes were used to measure the activities of the rectus abdominis, external oblique, and erector spinae muscles and those of the transversus abdominis and lumbar multifidus muscles, respectively. The lifting tests were performed in three different settings: lifting an expected 1.0 kg object; an unexpected 4.0 kg object (erroneously recognized as 1 kg); and an expected 4.0 kg object.

Main Outcome Measures: Comparison was made among the muscle activities, each being induced when the participants lifted different weights of objects, by calculating the root mean square (RMS) at rest and % maximum voluntary contraction (MVC).

Results: When the participants were aware of the weight of the object to be lifted, the activities of the external oblique, transversus abdominis, erector spinae, and lumbar multifidus muscles were elevated immediately after lifting. While, the elevation of these activities was delayed ($P < .05$) after lifting.

Conclusions: Our findings of this study suggest that when participants lift an object much heavier than expected, their trunk muscles may not be able to function appropriately.

Keywords: Electromyography; Trunk muscles; Estimate; Feedforward; Low back pain; Rehabilitation;

Trunk Muscle Activity while Lifting of Objects with Unexpected Weights

Introduction

Low back pain (LBP) is one of the most frequent physical complaints worldwide. To address this problem, the guidelines for clinical evaluation of LBP have been established in various countries in the world (1). In these guidelines, no evaluation and treatment methods have been specified from the standpoint of physical therapy and no definitive views on the function of the trunk muscles, which is one of factors playing an important role in lifting, have been set forth.

However, to control the trunk stably, the muscle activities of the trunk muscles, especially the deep-seated muscles are essential (2,3) and it has been verified that feedforward control of the trunk muscles occur prior to any motion(4).A study has reported that the subject make a change in responses of the trunk muscles depending on the weight of the object to be lifted for the stable control of the trunk muscles (5).

On the other hand, various factors such as the delayed contraction of the transverses

abdominis muscles, which are the deep-seated muscles of the trunk muscles and the attenuated muscle activities of the back muscles (6), including psychological factors such as fear-avoidance cycle (7), have the potential effects on chronic LBP.

The causes of etiology include lifting objects heavier than expected and taking unintentional behavior (8, 9). Although the mechanism of unstable control of the trunk muscles may be assumed from various aspects, the reaction of the body trunk muscles has not been clarified. A previous study has reported that the muscle activities of the trunk muscles, especially of the back muscles occur when an object is lifted with one hand (10) while almost no studies have reported on the reactions of the trunk muscles when the subject lifted an object heavier than expected.

Against this background, to reveal the effects of anticipation of the weight of an object to be lifted on the trunk muscles, this study analyzed the muscle activities of the trunk muscles occurring when an object heavier than expected was lifted using surface electrodes and wire electrodes, and conducted a comparative study.

Participants and Methods

1. Participants

Eleven adult men without LBP at the start of the study, who provided us with their informed consent, were enrolled in this study (age, 24.0 ± 2.2 years; height, 172.1 ± 6.6 cm; weight, 67.2 ± 7.9 kg; all right-handed; right arm length, 71.8 ± 5.1 cm). The exclusion criteria included a history of lumbar spine disorder, neurological disorder, and/or spine surgery.

This study was conducted in the presence of an orthopedic surgeon and was approved by the Ethics Committee of the Waseda University Faculty of Sport Sciences (Approval No. 08-027).

2. Tests

The test was started on the participant, who had sat up straight on a stool (in an erect sitting posture) with the bottoms of his feet in contact with the floor surface (and the knee joints and hip joints 90-degree flexed). The upper right limb grasped an object

on a table with the elbows straight and the upper left limb naturally dropped downward along the body side. Each participant was instructed to lift an object on the table up to the eye level with his right arm in response to a light stimulus (lifting test).

The five steps of the test procedure were sequentially performed (Table 1.)

Two kinds of materials of the same size but different weights, 1.0 kg of sand and 4.0 kg of lead, were used for the objects to be lifted. These materials were put in the same containers to make it impossible to distinguish between them based on their external appearances.

3. Electromyography

The activities of 10 types of muscles were measured including the right and left rectus abdominis, external oblique, transverses abdominis, lumbar multifidus, and erector spinae.

The EMG signals of the muscles of bilateral transverses abdominis and lumbar multifidus were recorded using fine-wire bipolar electrodes fabricated from two strands

of urethane-coated stainless-steel wire (diameter, 0.05 mm; Unique Medical Co, Ltd, Tokyo, Japan).

The fine wire was threaded into hypodermic needles (23 gauge \times 60 mm) with 2 mm of urethane cut off and the tips bent back to form 1- and 2-mm hooks. Wire electrodes were sterilized in an autoclave (HighClave HVE-50; Hirayama Manufacturing Corp, Saitama, Japan) at 121°C for 20 minutes. The electrodes were inserted into the muscles of bilateral transverses abdominis (approximately midway between the rib cage and the iliac crest) (11) and lumbar multifidus (approximately 2 cm lateral to the L5 spinous process) (12) under the guidance of ultrasound imaging. Once the electrodes reached the targeted muscle, it was stimulated by an electrical stimulation and muscle contraction was visually confirmed by ultrasound imaging.

Before the surface electrodes were attached, the skin was rubbed with a skin abrasive and alcohol to reduce the skin impedance to the level below 2 k Ω . Pairs of disposable Ag/AgCl surface electrodes (Vitrode F-150S; Nihon Kohden Corporation, Tokyo, Japan) were bilaterally attached, parallel to the muscle fibers, with a center-to-center distance of 2 cm, to the following muscles: the rectus abdominis (3 cm lateral to the

umbilicus) (13-15), the external oblique (midway between the costal margin of the ribs and the iliac crest (approximately 45° to the horizontal)(15,16), and the erector spinae (3 cm lateral to the L3 spinous process)(14,17). A reference electrode was placed over the sternum.

4. Tests on Maximum Voluntary Contraction

For normalization of the EMG data, a test on maximum voluntary contraction (MVC) was performed on the individual muscles of interest while the EMG signal amplitude was recorded. The test positions were consistent with those demonstrated in manual muscle testing books commonly used by physical therapists, but in some cases additional manual resistance was applied. Manual resistance was applied gradually, with the maximum level held for 3 seconds. Correct electrode placement was further confirmed by observing the EMG signal amplitude during the manual muscle tests.

For the rectus abdominis muscles, MVC was measured in a partial sit-up posture with the knees flexed, hands behind the head, and the trunk flexed, while resistance was applied onto the shoulder in the trunk extension direction. For the external oblique

muscles on the right side, the participants were in a supine position with their knees flexed and hands behind the head, while trunk was being flexed and rotated to the left. Resistance was applied onto the shoulders in the trunk extension and right rotation directions. For the external oblique muscles on the left side, the trunk was, instead, flexed and rotated to the right, with the resistance applied onto the shoulders in the trunk extension and left rotation directions. The MVC levels for the muscles of lumbar multifidus and erector spinae were measured with prone trunk extension while resistance was being applied onto the upper thoracic area in the trunk flexion direction. MVC for the transverses abdominis muscles was recorded when a maximal expiratory maneuver occurred with the abdominal hollowing in a sitting position (18, 19). Similar verbal encouragements were given to eleven participants for each of the MVC tests to ensure full extent of their power throughout the 3 seconds, and after the MVC test, the participants were asked if they thought it required full extent of their power. If not, the MVC was repeated. The MVC tests were performed at the intervals of one minute.

EMG data were collected for the 3-second period of isometric phase. The MVC level was calculated for the 1-second period, in which the highest signal activity was observed.

5. Measurement and data analysis

The electrical signals obtained from the individual electrodes during the period from the delivery of the light stimulus to the end of the lifting test were converted to the digital values at a sampling frequency of 1000 Hz to import into a personal computer.

To normalize the muscle activities, MVC was measured for each of the muscles; the root mean square (RMS), which showed the muscle activity, was calculated. During the baseline measurement, RMS was calculated for the 50-ms period (20), during which the participant held the object with his right arm and muscular potential was stable (at rest). During each of the lifting tests, the time points when the object left the table and the sensor potential decreased were defined as 0 ms and RMS analysis was performed during the period from -200 to +200 ms. This period was divided into eight 50-ms phases and RMS was calculated for each of these 8 phases. The RMS value calculated in this way was divided by the RMS at the time of MVC to find % MVC. A comparison was made between the muscle activities by calculating the RMS at rest and %MVC, which was obtained by dividing the RMS for each of the 8 phases of the individual

lifting tests by the RMS at the time of MVC.

6. Statistical analysis

For each of the muscles, comparisons were made between activities at rest and those during the individual phases, as well as between the tests for each phase. In comparison, ANOVA was used and if a significant difference was observed in any of test items, the Dunnett's multiple comparison test was conducted.

Statistical analyses were performed using SPSS (15.0). In all analyses, $P < .05$ was regarded as statistically significant.

Results

Abdominal muscles (Fig.1.)

Relative to the baseline % MVC, no significant difference were observed between the

muscles of rectus abdominis and external oblique. There was no significant increase in the muscle activities of the transverses abdominis muscles did not significantly increase during lifting of the expected 1 kg object. However, when the participant lifted the expected 4 kg object, a significant increase in the muscle activity of right transverses abdominis was recorded during Phases 5 and 6 (immediately after the start of the lifting test). Increases were also observed in the muscle activity of right external oblique and left transverses abdominis during Phases 5 through 7. When the participant lifted the unexpected 4 kg object, a significant increase was observed only in the muscle activity of right transverses abdominis during Phase 8.

Back muscles (Fig.2.)

Relative to the baseline % MVC, both of the muscle activities of the erector spinae and lumbar multifidus muscles significantly increased during Phases 3 and 4 (immediately before the start of the lifting test) in each of the three-different test settings. Furthermore, these back muscle activities also increased during Phases 5 through 7 when the participant lifted the expected 4 kg object. When the participant lifted the expected 1.0 kg or unexpected 4 kg object, no significant increase in the muscle activity

was recorded during Phase 5 (immediately after the start of the lifting test), but the muscle activities of the right erector spinae and right lumbar multifidus muscles increased during Phases 6 through 8, while those of the left erector spinae and left lumbar multifidus muscles increased during Phases 7 and 8.

Discussion

We investigated paraspinal muscle activities during three-different lifting tests: 1) the participants were aware of the object's actual weight, which was 1 kg (expected 1 kg); 2) the participants believed the object's weight was 1 kg, but it actually weighed 4 kg (unexpected 4 kg); and 3) the participants were aware of the object's actual 4 kg weight (expected 4 kg).

The present study revealed that in the expected 1 kg test, the activities of back muscles (erector spinae and lumbar multifidus) increased only during Phases 3 and 4 (-200 to 0 ms) before the start of the lifting test with no increase during the subsequent phases. On the other hand, none of the abdominal muscles showed increased activities

during any of the phases, which is consistent with the results of a previous study on muscle activity latency (21). Our findings suggest that when the participant lifts a light object, only back muscle activities increase before lifting. According to a previous report, the central nervous system (CNS) controls the coordinated-contraction activities of the transverses abdominis and lumbar multifidus muscles based on the prediction of motions (22). The increase in these muscle activities before lifting might be controlled by CNS.

In the expected 4 kg test, the muscle activities increased before lifting an object in the same way as in the expected 1 kg test; however the muscle activities of right external oblique and transverses abdominis muscles increased significantly after lifting during Phases 5 through 7 (0-150 ms) as compared with those in the expected 1 kg test (Fig. 1).

When the participant lifts an object after having been aware that the object is heavy, trunk stabilization can still be achieved via elevated activities of the back and abdominal muscles immediately after lifting. In the unexpected 4 kg test, the activities of abdominal muscles were similar to those in the expected 1 kg test during all phases recorded. However, back muscle activities in the unexpected 4 kg test followed a course

similar to those in the expected 1 kg test until Phase 5 (-200 to 50 ms), while the activities of erector spinae and lumbar multifidus muscles after Phase 6 (50-100 ms) were higher than those in the expected 1kg test. This suggests that the onsets of erector spinae and lumbar multifidus muscle contraction were delayed in the unexpected 4kg test as compared with those in the expected 4kg test (Fig. 2).

In general, the activities of the lumbar multifidus muscles begin with a short latency response to stimuli and spread in a bilateral and multi-segmental manner (23-25). The activated motor cortex may induce the postural control of the trunk muscles for stable spine. In the present study, CNS's failure to appropriately function in the unexpected 4 kg test might cause a delay in muscle activities of the back muscles.

It has been reported that feedforward control of the deep-seated muscles is delayed in the patients with LBP (4) and in the patients with unstable lumbar spine, feedforward reaction of the erector spinae muscles is delayed (26). According to these reports and our findings, we postulate that this delay of muscle activities in the unexpected 4kg test may be related to the development of LBP.

We conducted this study in a sitting posture to eliminate the influence of lower limbs motion. Pre-training or priming was conducted on the participants in this study. Thus, it is not completely simulate the lifting motion in the real world. These are the limitations of this study.

Conclusion

The findings of this study suggest that when an unexpectedly heavy weight of object is lifted, the trunk muscles may not function appropriately. We hypothesize that these findings might be related to the LBP onset, however further investigation is needed.

Ethical approval: Waseda University Faculty of Sport Sciences (Approval No. 08-027).

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Conflict of interest: None declared.

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Fig.1

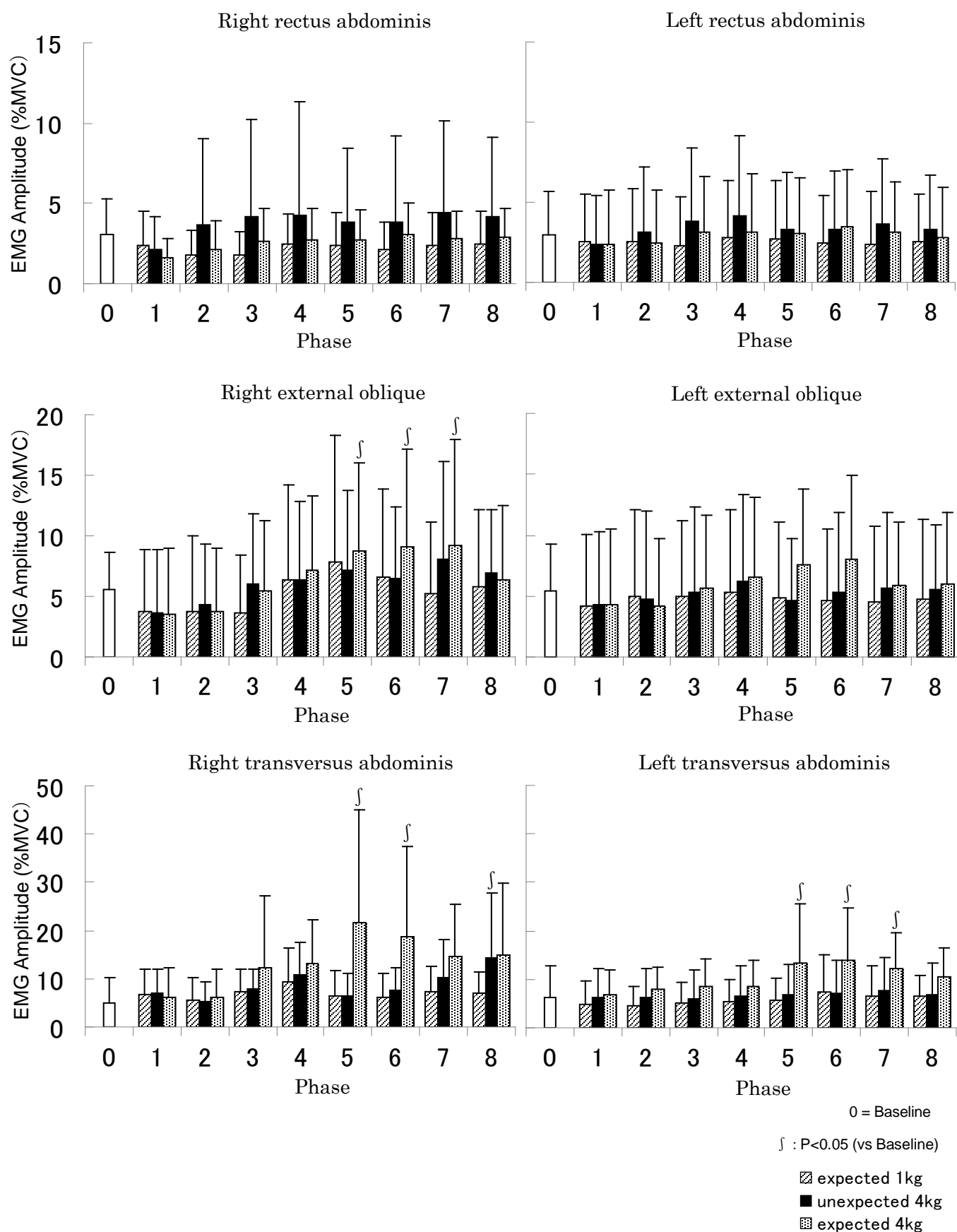


Fig.2

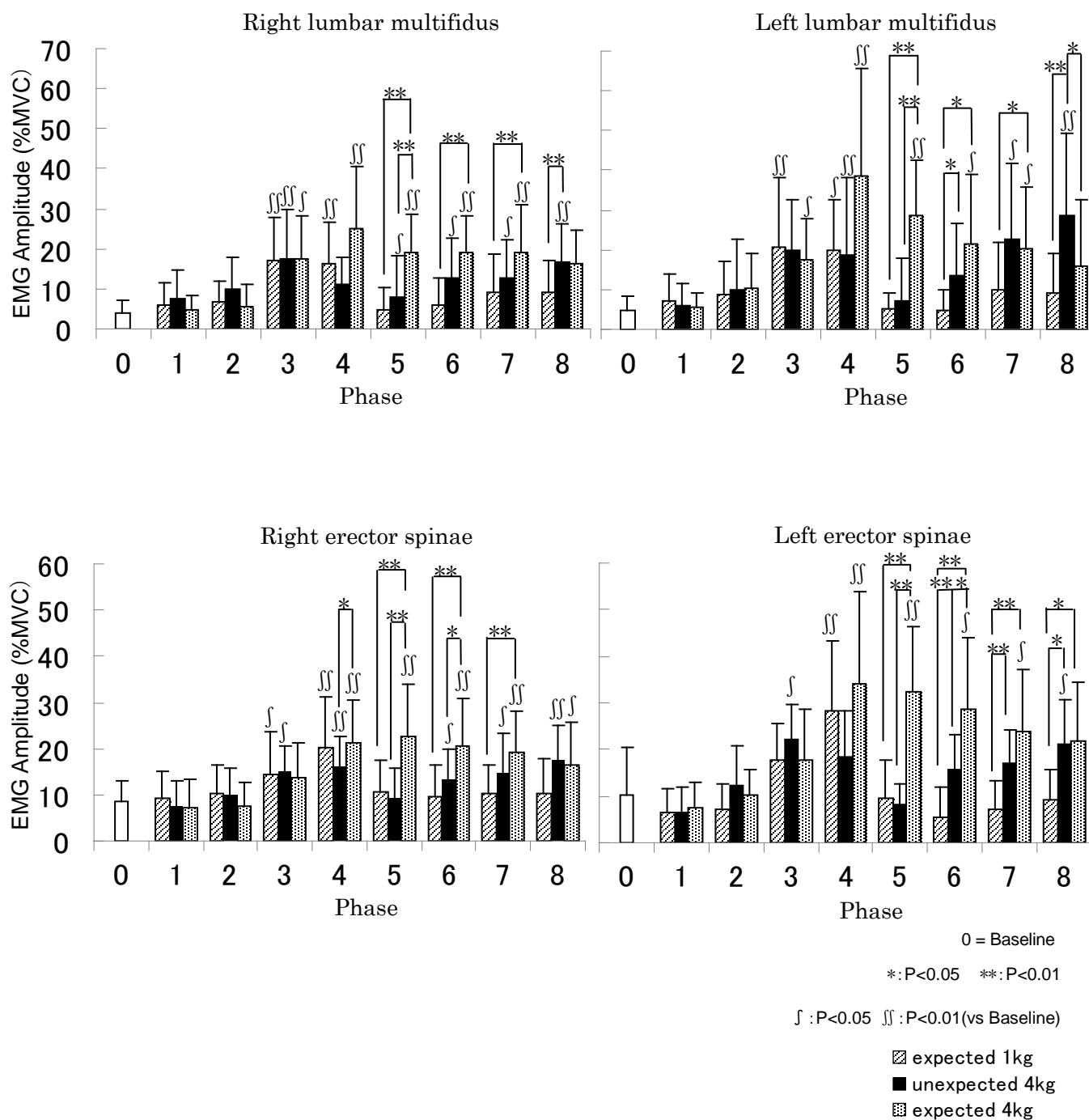


Figure legend

Fig. 1. Abdominal muscles

In the expected 4.0 kg test, a significant elevation was observed in the muscle activities of the right external oblique and left and right rectus abdominis muscles relative to the baseline (at rest) immediately after lifting. In the unexpected 4.0 kg test, the muscle activities at rest were at the same level as that obtained from the expected 1.0 kg test with no significant difference but a significant elevation in the muscle activities of the right rectus abdominis muscle in Phase 8.

Fig. 2. Back muscles

In all the tests, a significant elevation was observed in the muscle activities relative to the baseline (at rest) immediately before lifting (Phases 3 and 4). In the expected 4.0 kg test, an elevation was observed in all the muscle activities immediately after lifting (Phase 5). In the unexpected 4.0 kg test, the muscle activities were at the same level as that obtained from the expected 1.0 kg test up to Phase 5 with no significant difference but a significant elevation in Phase 6 and its subsequent phases.

Table 1. The five test steps

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|---|--|
| (1). Recognizing a 1.0 kg object | The participant lifted an object of 1.0 kg as expected 10 times to achieve familiarization with the expected 1.0 kg weight. The repetitive trials allowed the participants to learn the most appropriate way to lift the object. |
| (2). Lifting the expected 1.0 kg object and measuring the muscle activities | An object identical to that used in the step (1) in external appearance and weight was placed on the table and the muscle activities were measured while the participant lifted it (one session). A sensor was placed between the table and the object to immediately detect the removal of the object from the table, generating an electromyographic signal. |
| (3). Lifting the unexpected 4 kg object and measuring the muscle activities | An object identical to that used in the step (1) in external appearance but different in weight (4.0 kg) was placed on the table and the muscle activities were measured while the participant lifted it. The participant had not be aware of a difference in weight between this object and that used in the step (1). |
| (4). Recognizing the 4.0 kg object | The participant lifted an 4.0 kg object placed on the table 10 times to achieve familiarization with the 4 kg weight as expected. |
| (5). Lifting the expected 4 kg object and measuring the muscle activities | An object identical to that used in the step (4) was placed on the table and the muscle activities were measured while the participant lifted it. |